Distributed Systems Lecture 13

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Security

- Security comprises:
  - **Confidentiality:** No unauthorized disclosure of information
  - **Integrity:** No accidental or malicious alteration of information
- To provide security, encrypt and decrypt messages using keys
- Two different approaches and kinds of keys
  - **Secret key:** Use a single shared secret key to encrypt and decrypt messages sent between Alice and Bob
  - **Public/private key:** Each party has his/her own public key and private key
    - Alice encrypts a message *m* that she sends to Bob with Bob's public key K_B^+
    - Bob decrypts an encrypted message that he receives from Alice with Bob's private key K_B^-

Security

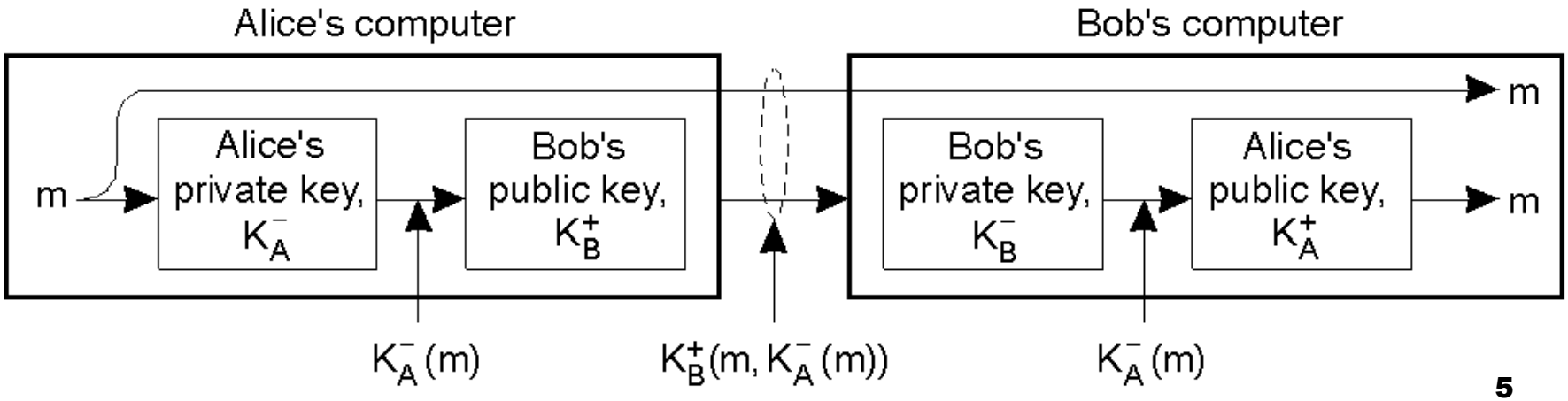
- **Several problems with keys**
  - **Keys wear out:** The more data that are encrypted with a single key, the easier it is to discover the key => *don't use keys too often*
  - **Compromised keys:** If a key is compromised, you can't use it again => *don't use the same key for all communication*
  - **Long-lived keys:** Untrusted entities might play along and behave properly for a while, but not forever
    => *don't use the same key forever; make keys disposable*
  - **Message replay:** Using the same key for different sessions allows old messages to be inserted into the current session
    => *use a different key for each session /connection*
- Don't use valuable and expensive (in encryption/decryption) keys for all communication, but only for **authentication**

Authentication

- In addition to security, we need:
  - **Authentication:** The receiver can verify the claimed identity of the sender
  - **Non-repudiation:** The sender cannot later deny that he/she sent the message
- To provide authentication and non-repudiation, have the sender sign all messages he/she transmits using a **digital signature** such that:
  - The signature can be verified, and
  - The message and signature are uniquely associated

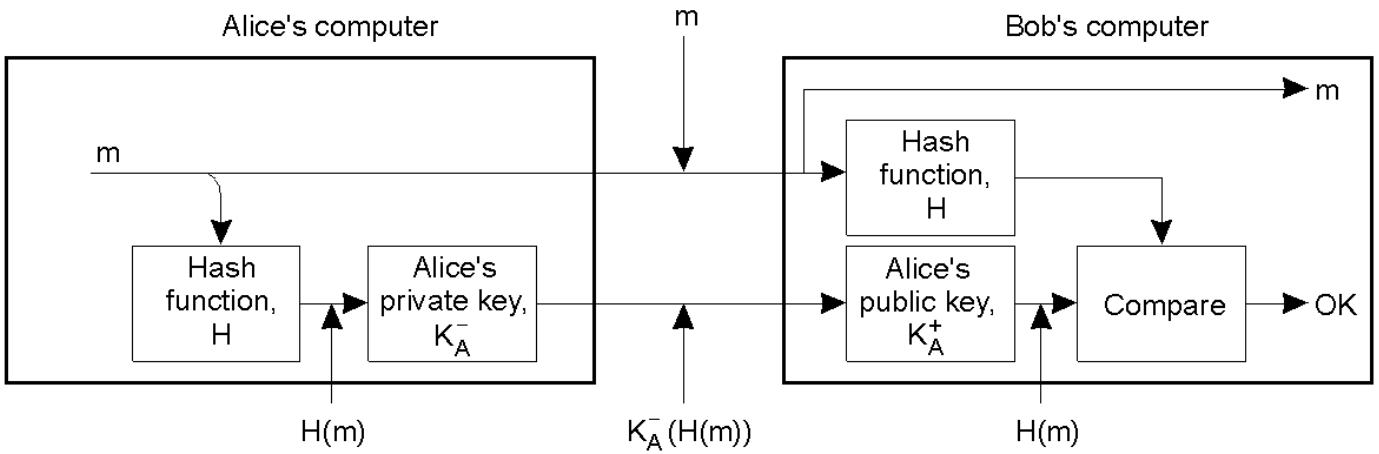
Digital Signatures

- Encrypting a message using public-key cryptography to provide both **authentication** and **security**
  - **Alice signs the message using her private key K_A^-**
  - **Alice encrypts the message using Bob's public key K_B^+**
  - **Bob decrypts the message using his secret key K_B^-**
  - **Bob decrypts Alice's signature using Alice's public key K_A^+**



Digital Signatures

- To improve performance, don't mix security and authentication
- Instead, have the sender transmit the message in the clear, but **sign a message digest** using his/her digital signature
  - **Alice takes a digest of message m using a hash function H, such as MD5**
  - **Alice signs the message digest using her private key K_A^-**
  - **Bob takes a digest of message m using the same hash function H**
  - **Bob decrypts the encrypted digest using Alice's public key K_A^+ and compares it with the digest he just computed**

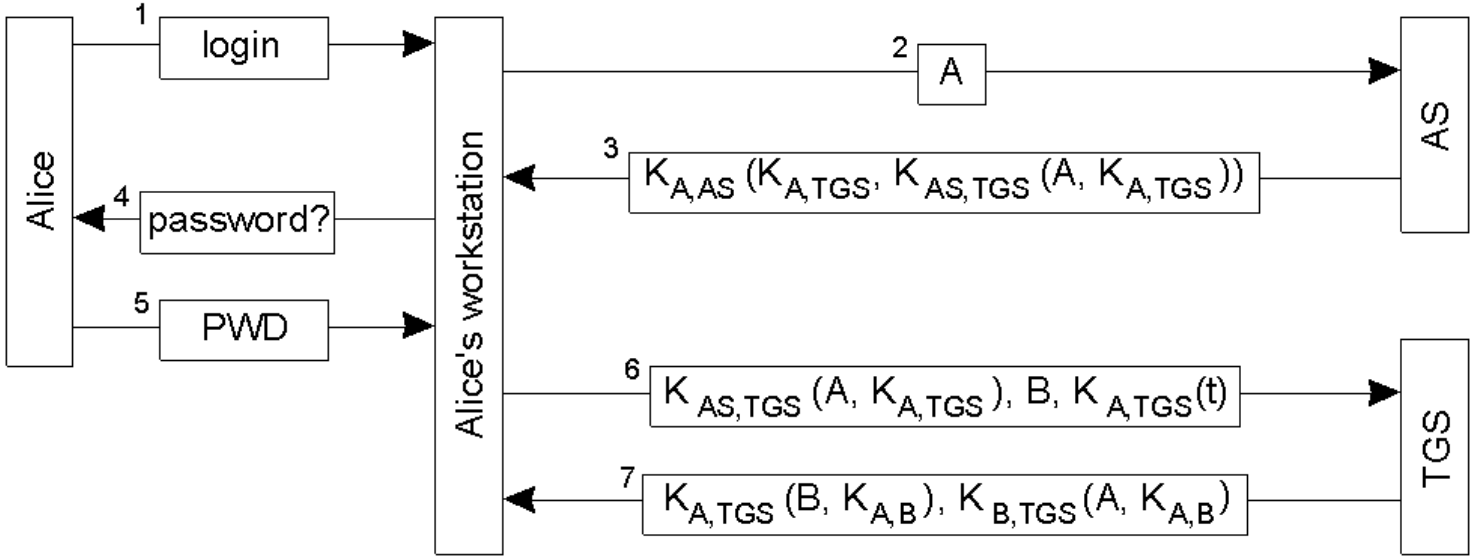


Example: Kerberos

- Authentication in **Kerberos** (a security system that helps clients to set up a secure channel with any server, developed at MIT, uses Needham-Schroeder authentication)

(2) Alice's workstation sends Alice's identity A to the Authentication Server (AS)

(3) AS sends back information to allow Alice to communicate with the Ticket Generating Service (TGS)

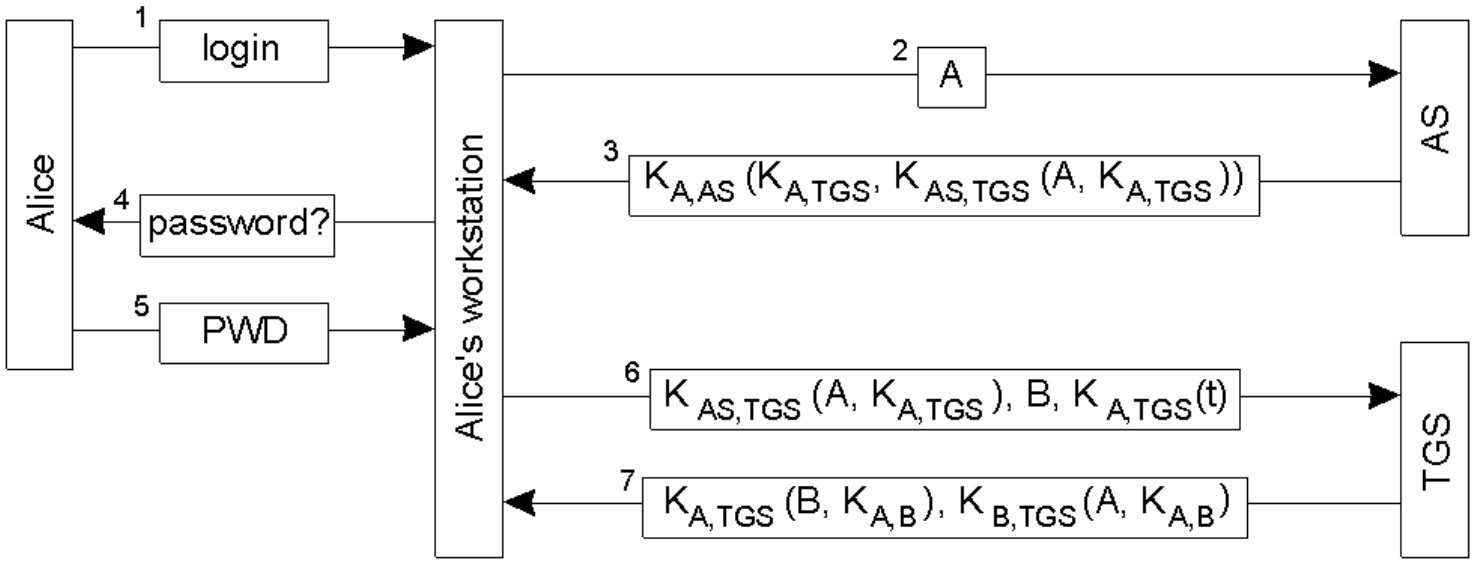


Example: Kerberos

(5) Alice's password is converted into a key $K_{AS,TGS}$ which Alice uses to communicate with the TGS

(6) Alice's workstation sends a request to the TGS for a session key $K_{A,B}$ to be used for communication with Bob

(7) The TGS sends back the session key $K_{A,B}$, encrypted with the key $K_{A,TGS}$ for Alice and encrypted with the key $K_{B,TGS}$ for Bob



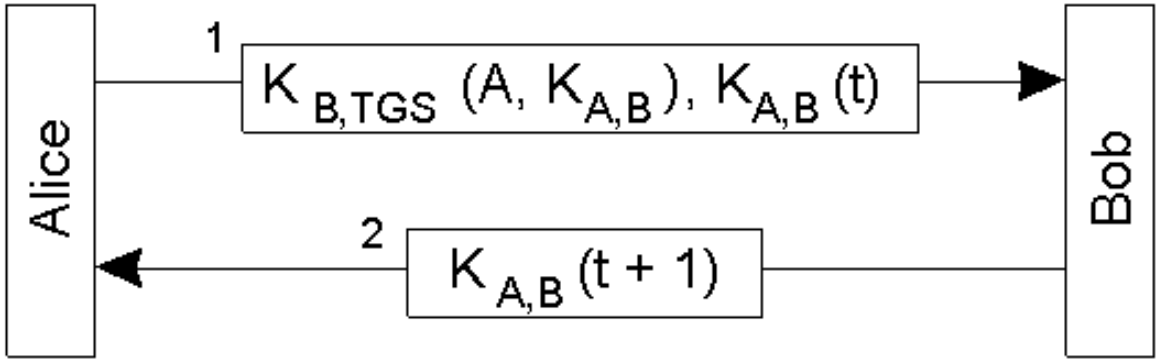
Example: Kerberos

- Setting up a secure channel in Kerberos

  (1) Alice sends her identity A and the session key $K_{A,B}$ encrypted with the key $K_{B,TGS}$ for Bob and also a nonce t encrypted with the session key $K_{A,B}$

  (2) Bob returns the nonce encrypted with the session key $K_{A,B}$

- **Note:** Alice obtained $K_{B,TGS}(A, K_{A,B})$ from the TGS (on the previous slide)

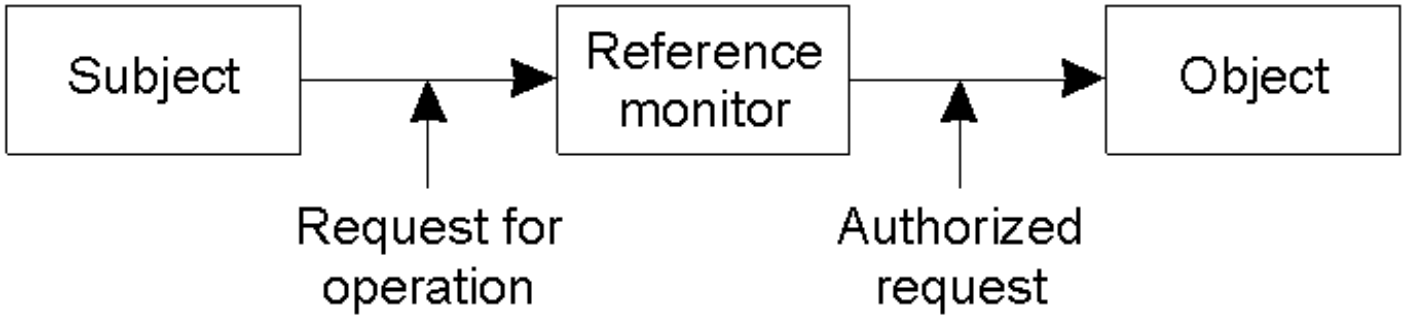


Access Control

- Authorization
- Access Control Matrix
- Protection Domain
- Firewall
- Secure Mobile Code

Authorization

- We need not only authentication but also authorization
  - **Authentication:** Verify that a subject says that he/she is who he/she claims to be, i.e., verify the identity of the subject
  - **Authorization:** Determine whether a subject is permitted to use certain data/operations of an object
- Authorization makes sense only if the requesting subject has been authenticated first



Access Control Matrix

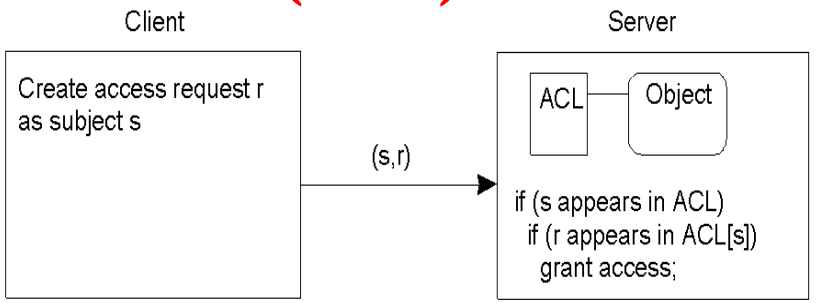
- Maintain an **Access Control Matrix (ACM)**
  - ACM[S,O] contains the permissible operations that subject S can perform on object O

(a) An object O maintains an **Access Control List (ACL)**

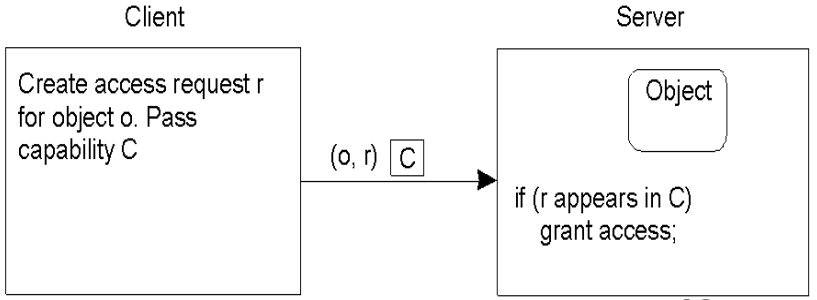
  - ACM[*,O] describes the permissible operations on O per subject (or group of subjects)

(b) A subject S has a **Capability List**

  - ACM[S,*] describes the permissible operations by S per object (or category of objects)



(a)



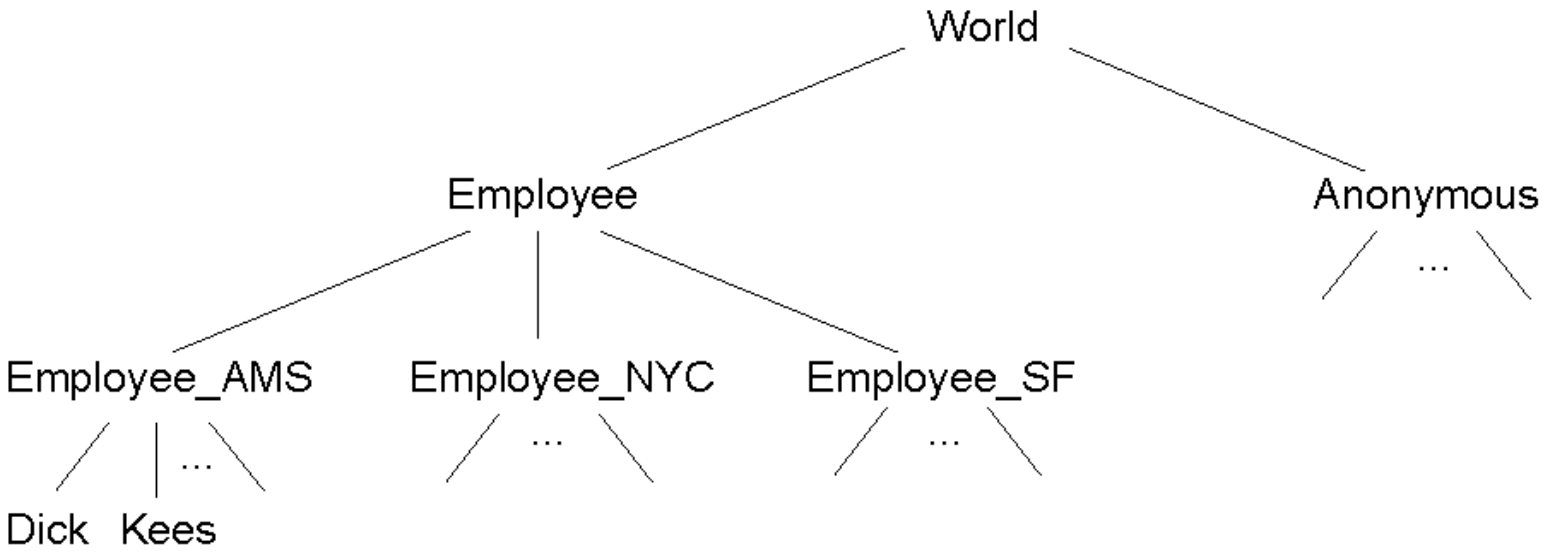
(b)

Protection Domain

- **Problem:** Access Control Lists and Capability Lists can be very large
- **Solution:** Reduce the amount of information that needs to be stored using **protection domains**
  - **An *(object, access rights)* pair is associated with a protection domain**
  - **For each access request, first look up the appropriate protection domain**
- Common implementations of protection domains
  - **Groups: Users belong to specific groups; each group has associated access rights**
  - **Roles: Users have different roles; a user's role is determined at login time; a user's role may change**

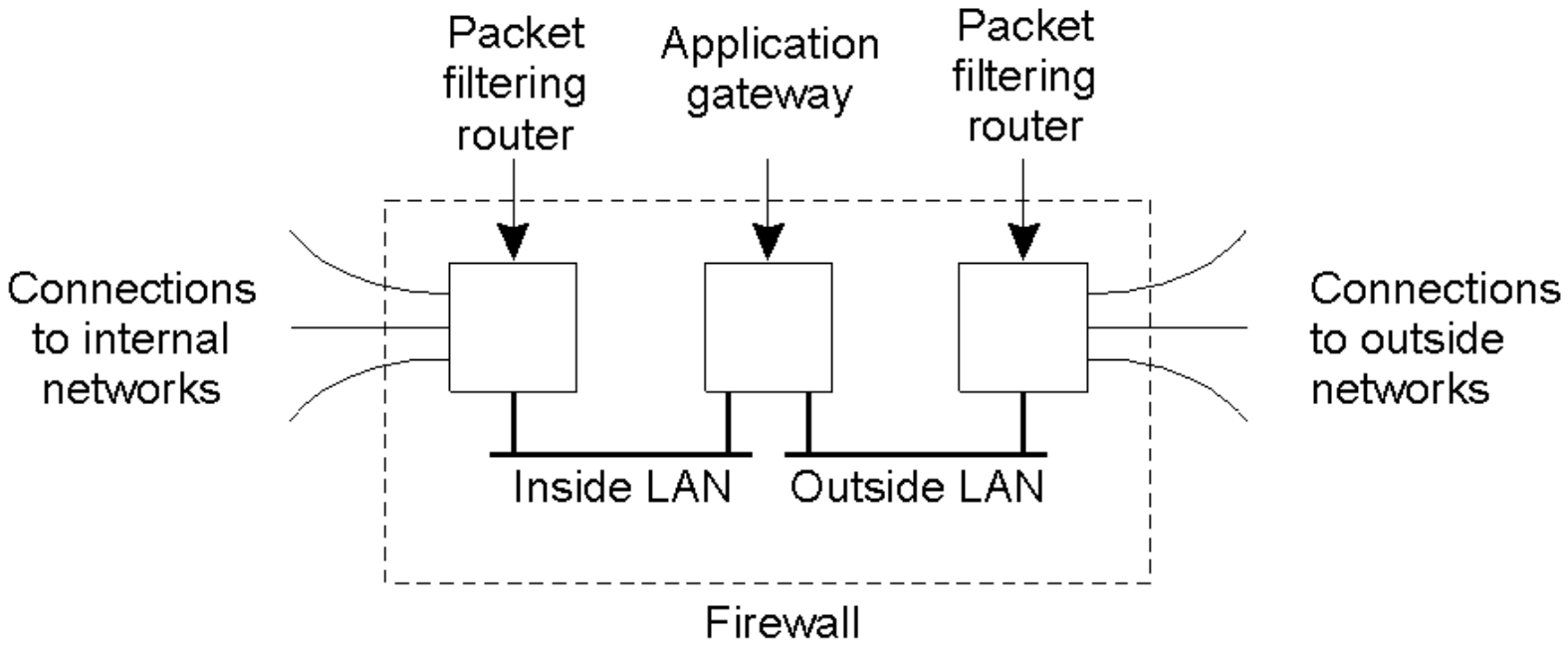
Protection Domain

- The hierarchical organization of protection domains, implemented as **groups** of users



Firewall

- Sometimes it's better to consider requests at the level of **packets**. Packets that do not satisfy certain requirements are simply removed from the channel
- A company is protected by a **firewall** that implements access control



Secure Mobile Code

- **Mobile code**, e.g., Java applets or Java aglets
- If the data are very large, it makes sense to move the code to the data, rather than move the data to the code
  - **The remote node (host) needs to be protected against malicious mobile code**
  - **The mobile code needs to be protected against a malicious host**

Protecting the Host

- First, distinguish local code from remote code
- Assign a set of permissions to mobile code before it is executed and check operations against those permissions
- Assign different sets of permissions to different units of mobile code => *authenticate mobile code using signatures*

Protecting the Host

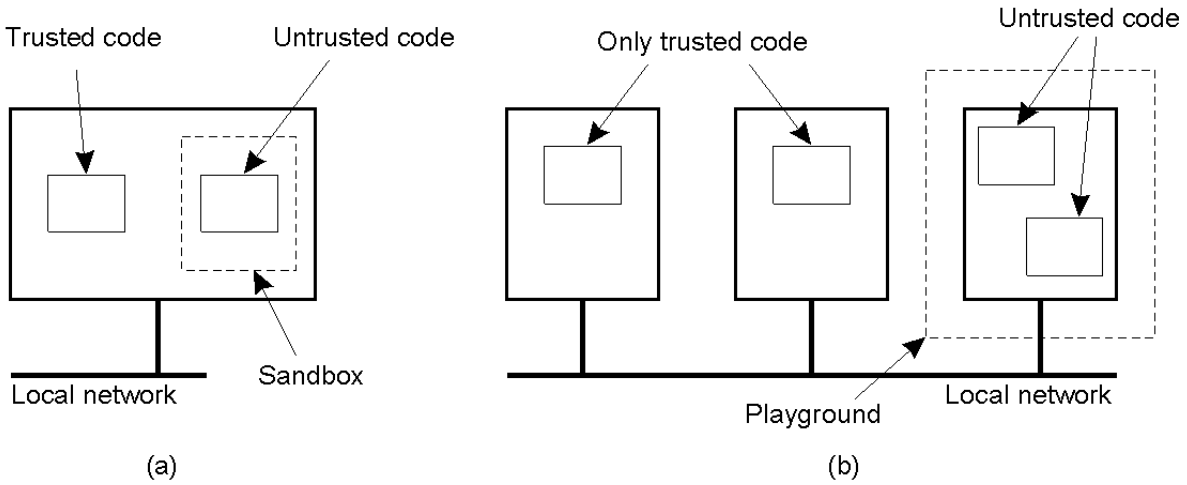
- Enforce a single strict policy, and implement the policy using a few simple mechanisms

(a) Sandbox model

- **Policy: Remote code is allowed to access only a pre-defined set of resources and services**
- **Mechanism: Check instructions for illegal memory access and service access**

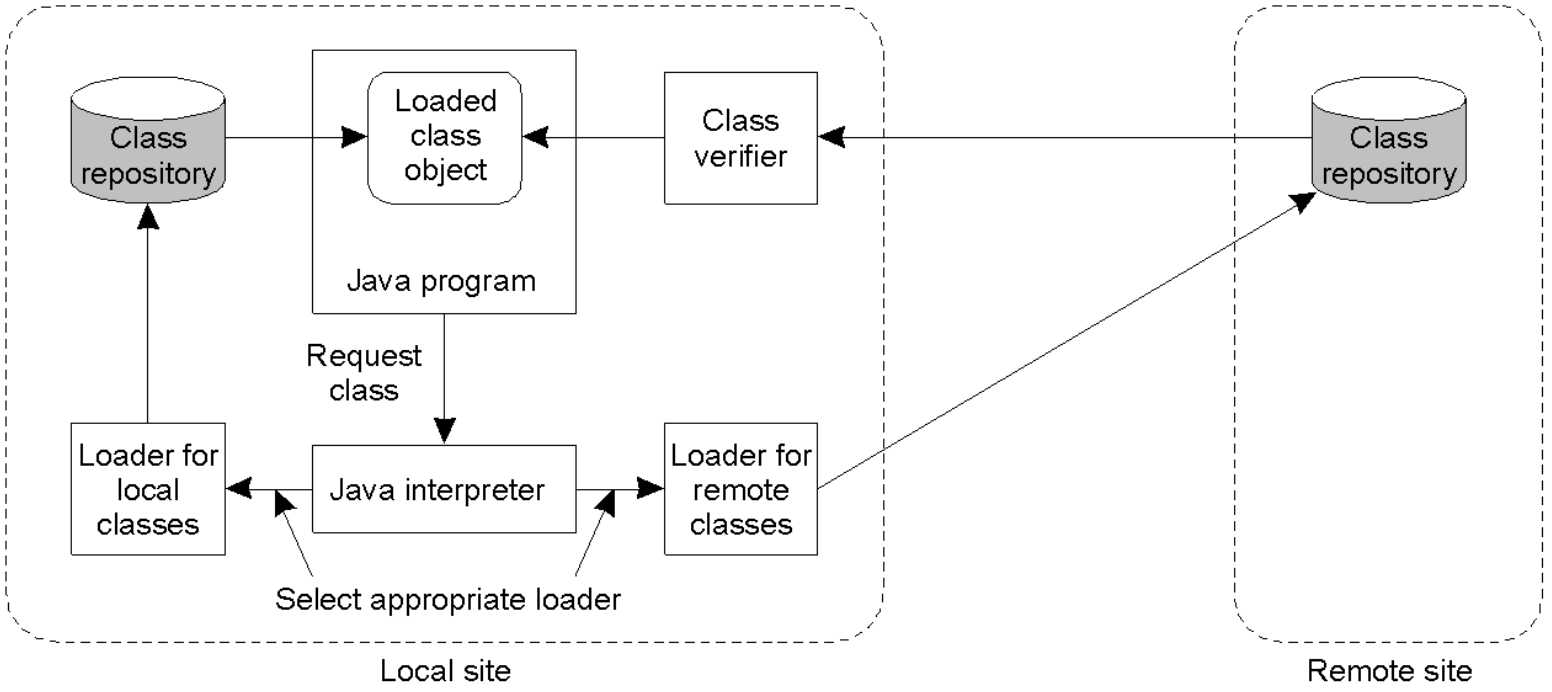
(b) Playground model

- **Policy: Same**
- **Mechanism: Run code on a separate "unprotected" machine**



Protecting the Host

- A Java sandbox for Java applets, aglets, etc.



Protecting the Mobile Code

- **Example Ajanta:** A mobile code (agent) system that detects whether mobile code has been tampered with, while it is on the move
- Most important, **append-only logs**
  - **Data can be only appended, not removed**
  - **Data has an associated checksum**
  - **Initially, the checksum has the value**

$$C_{init} = K^{+}_{owner}(N) \text{ with nonce } N$$

  - **When a server *S* adds data *X* to the log**

$$C_{new} = K^{+}_{owner}(C_{old}, sig(S,X), S)$$

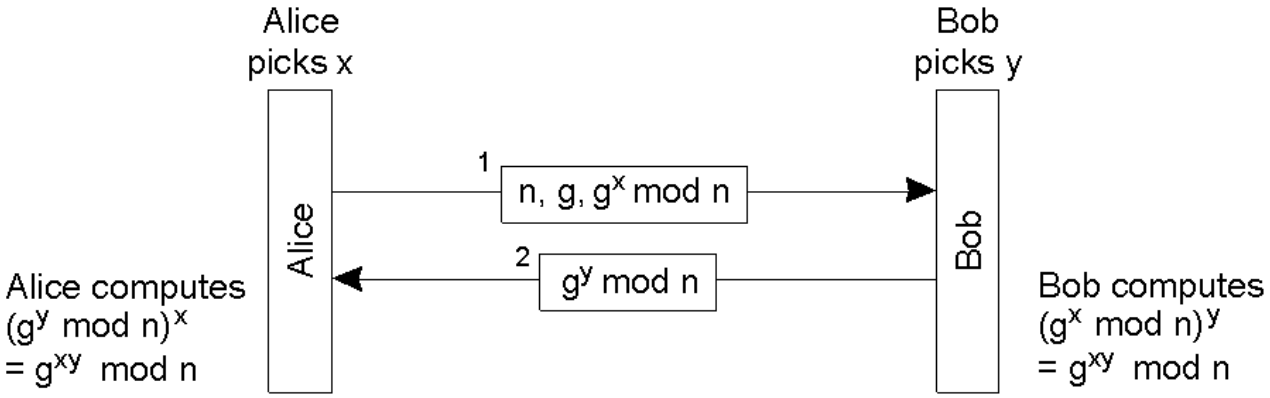
where *sig*(*S*,*X*) indicates server *S* has signed data *X*

Security Management

- Key establishment
- Key distribution
- Secure group management
- Authorization management

Key Establishment

- **Diffie Hellman Key Exchange:** Construct a shared secret key $K_{A,B}$ in a safe way *without* having to trust a Key Distribution Center, as follows:
  - **Alice and Bob must agree on two large numbers, *n* and *g*, which are regarded as public**
  - **Alice chooses a large number *x*, which she keeps private Bob chooses a large number *y*, which he keeps private**



(1) Alice sends (n, g, g^x mod n) to Bob

(2) Bob sends (g^y mod n) to Alice

(3) Alice computes $K_{A,B} = (g^y \bmod n)^x = g^{xy} \bmod n$

(4) Bob computes $K_{A,B} = (g^x \bmod n)^y = g^{xy} \bmod n$

Key Distribution

- If authentication is based on cryptographic protocols and session keys are used to establish secure channels, who is responsible for handing out the keys?

(a) Secret keys: Alice and Bob need to get a shared secret key

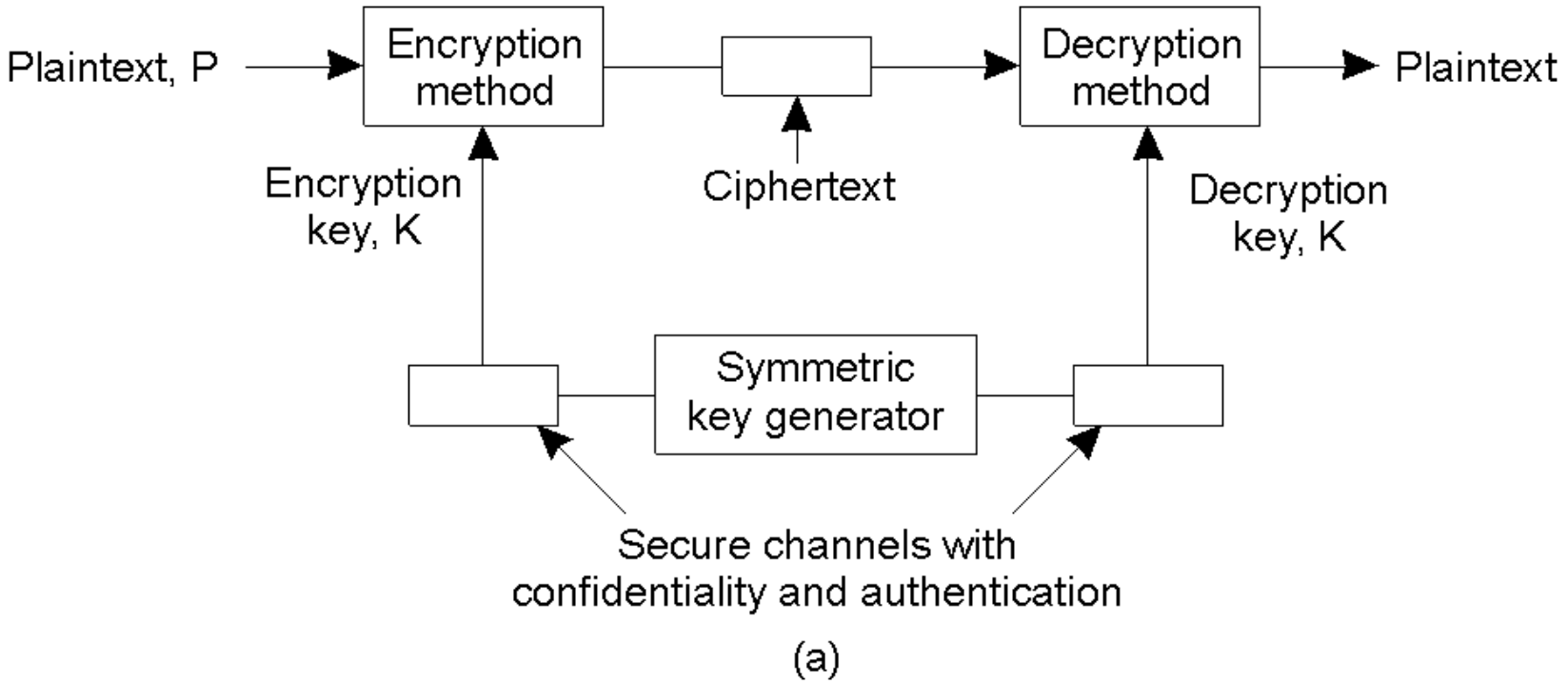
- **They can invent their own shared secret key as on the previous slide, or**
- **They can ask a trusted Key Distribution Center (KDC) for a key as in the previous lecture**

(b) Public keys: Alice needs Bob's public key to decrypt (signed) messages from Bob, and Bob needs a private key to encrypt messages that he sends to Alice

- **But, how does Alice know that it is indeed Bob who owns the public key**
- **They can use a trusted Certification Authority (CA) to hand out each key, by putting it in a certificate signed by the CA**

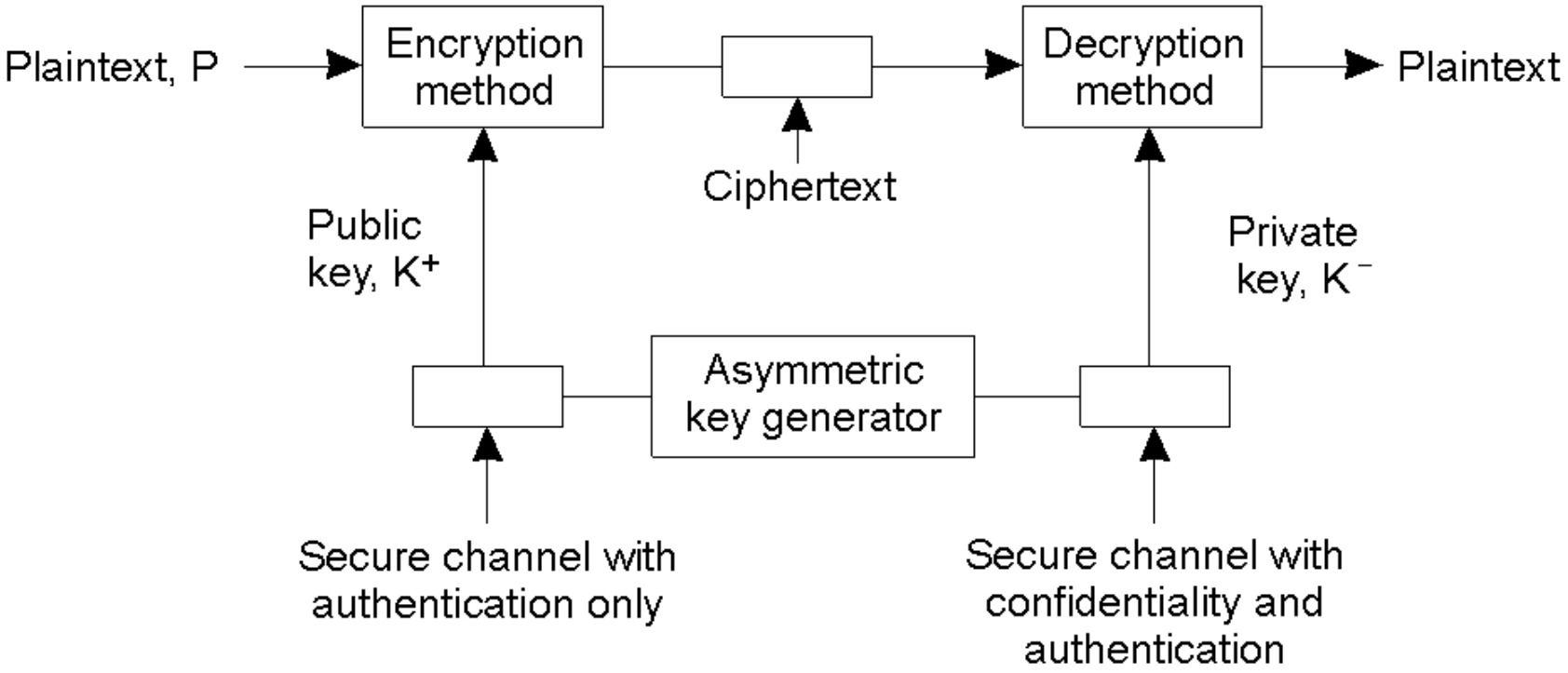
Key Distribution

(a) Secret key distribution



Key Distribution

(b) Public key distribution

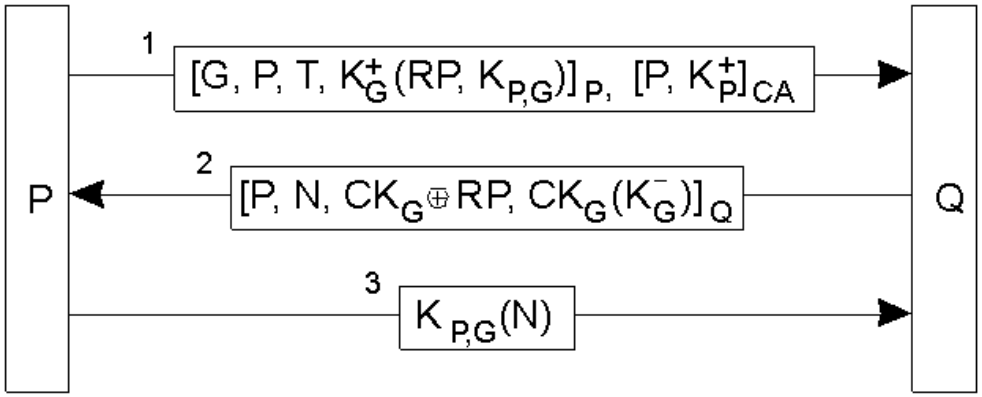


(b)

Secure Group Management

- A group G of processes uses:
  - **A key pair (K^+_G, K^-_G) to communicate with non-group members**
  - **A shared secret key CK_G to communicate with group members**
- Process P wants to join the group G; process Q is a member of G

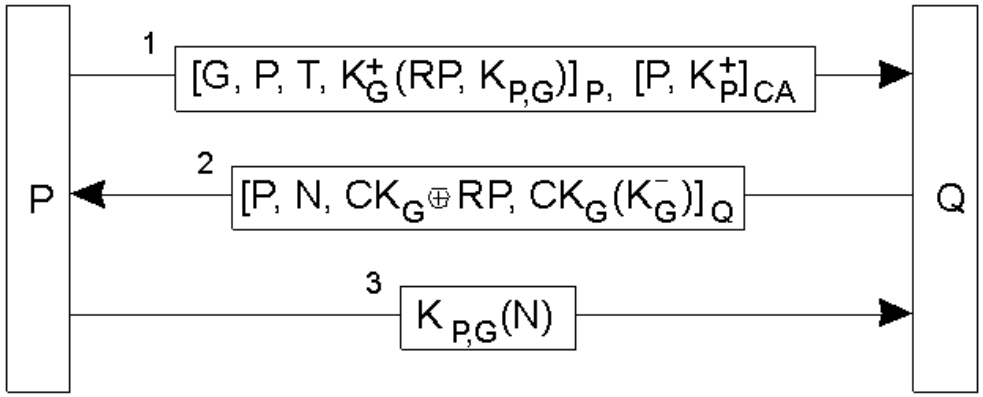
  (1) P generates a one-time ReplyPad RP and a secret key $K_{P,G}$
  P sends a JoinRequest JR to Q signed by P (notation: $[JR]_P$), along with a certificate containing its public key K^+_P



Secure Group Management

(2) Q authenticates P and checks whether P can be allowed to join G
Q returns a nonce N, the group key CK_G XORed with RP, and
the group private key K^-_G encrypted with CK_G

(3) P authenticates Q and sends back the nonce N encrypted with $K_{P,G}$, letting Q know that it has all the necessary keys



Authorization Management

- To represent the access rights of a user, we use **capabilities**
  - **11111111 represents full access rights, and 00000001 represents very limited access rights**
  - **The capability includes a random number C**
  - **When a restricted capability is issued, it is XORed with C and then it is run through a one-way function to generate a check code**
  - **When the restricted capability is used, the owner of the object verifies the check code before authorizing access**